FINAL REPORT

of the

ENGINEERING BOARD OF REVIEW

on the

COLORADO RIVER AQUEDUCT

to the

BOARD OF DIRECTORS

of

THE METROPOLITAN WATER DISTRICT

of

SOUTHERN CALIFORNIA

December 19, 1930

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FINAL REPORT

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MONITORING BOARD OF REVIEW

on the

FOURTH RIVER AQUEDUCT

to the

BOARD OF DIRECTORS

of

THE METROPOLITAN WATER DISTRICT

of

SOUTHERN CALIFORNIA

December 19, 1990

INDEX

APPENDICIES

MAP

SHOWING THE PRINCIPAL AQUEDUCT ROUTES

INDEX

APPENDICES

MAP

December 19, 1930.

Mr. W. P. Whitsett,
Chairman, Board of Directors,
The Metropolitan Water District
of Southern California,
Los Angeles, California.

Dear Sir:

On December 21, 1929, the undersigned members of the Engineering Board of Review, after a study of the various routes which had been proposed for an aqueduct from the Colorado River to The Metropolitan Water District of Southern California, submitted a preliminary report recommending the elimination of certain of these routes and designating others for further and more detailed surveys and geological examinations.

On November 14, 1930, after ten months of intensive work on the recommendations of this Board, a report was submitted by your Chief Engineer, Mr. F. E. Weymouth, and on November 25, 1930, this report was referred to us for final review and recommendation together with the following letter of instructions.

"To the Members of the Board of Review,
The Metropolitan Water District
of Southern California.
Messrs. Thaddeus Merriman,
Richard R. Lyman and
A. J. Wiley.

"Gentlemen:

"During the time elapsed since the filing of your preliminary report, Chief Engineer Frank E. Weymouth and his staff of engineers have been engaged

December 15, 1950.

Mr. W. F. Whitsett,
Chairman, Board of Directors,
The Metropolitan Water District
of Southern California,
Los Angeles, California.

Dear Sir:

On December 23, 1950, the undersigned members of the Engineering Board of Review, after a study of the various routes which had been proposed for an aqueduct from the Colorado River to The Metropolitan Water District of Southern California, submitted a preliminary report recommending the elimination of certain of these routes and deferring others for further and more detailed surveys and geological examinations.

On November 14, 1950, after ten months of intensive work on the recommendations of this Board, a report was submitted by your Chief Engineer, Mr. F. E. Weymouth, and on November 28, 1950, this report was referred to us for final review and recommendation together with the following letter of instructions.

"To the Members of the Board of Review,
The Metropolitan Water District
of Southern California.
Messrs. Huddleson Merriman,
Richard P. Lyman and
A. J. Wiley.

"Gentlemen:

"During the time elapsed since the filing of your preliminary report, Chief Engineer Frank E. Weymouth and his staff of engineers have been engaged

in securing the engineering and geological data requested. In addition, Mr. Weymouth has directed detailed studies on other phases of the aqueduct project, including an exhaustive investigation of the possibilities of bringing water from the Colorado River to the cities in the District by means of a gravity aqueduct.

"On November 14th, Mr. Weymouth filed with this Board his report and findings on the problem of selecting the safest, most economical and most practicable route for the aqueduct. In his report he presents the results of his surveys and studies on the four general routes selected by you for further investigation. Data and findings on other alternative routes also were submitted by Mr. Weymouth in his report.

"This Board, therefore, is prepared to advise you that all of the engineering and geological studies on the Colorado River Aqueduct project requested by you in your preliminary report have been made available by the Chief Engineer of The Metropolitan Water District, and are hereby referred to you for your information and use. Accordingly, all is in readiness for you to resume your study of the aqueduct problem--and to proceed to the making of your recommendations on this project.

"As you resume your duties as a Board of Review on this vitally important task of selecting the best and most economical route for the Colorado River Aqueduct, this Board desires to place before you the following final instructions and suggestions:

"1. At the time you originally were retained by this Board you were instructed to recommend to the Board an aqueduct plan which would assure the perpetual delivery of an adequate supply of water to The Metropolitan Water District at the lowest possible cost, all elements of construction and operation costs considered. It is desired to reiterate such instructions at this time.

"2. All data collected by Chief Engineer Weymouth and his staff of assistants, or secured by the District from any other source,

Mr. W. P. Whitsett. December 19, 1930.

in securing the engineering and geological data requested. In addition, Mr. Weymouth has directed detailed studies on other phases of the aqueduct project, including an exhaustive investigation of the possibilities of bringing water from the Colorado River to the cities in the District by means of a gravity aqueduct.

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"This Board, therefore, is prepared to advise you that all of the engineering and geological studies on the Colorado River Aqueduct projects requested by you in your preliminary report have been made available by the Chief Engineer of The Metropolitan Water District, and are hereby referred to you for your information and use. Accordingly, all is in readiness for you to resume your study of the aqueduct problem--and to proceed to the making of your recommendations on this project.

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"2. All data collected by Chief Engineer Weymouth and his staff of assistants, or secured by the District from any other source,

are made available to you. Mr. Weymouth's report and recommendations are referred to you for your information. You are advised, however, that the Board expects you to make an independent study of the aqueduct route problem. In no way are you to be bound by Mr. Weymouth's findings and recommendations.

"3. Should there be other data desired by you but not made available in the studies conducted by the Engineering Department of the District, such data will be supplied upon request.

"4. You are particularly instructed to give full consideration to the relative physical and economic merits of gravity flow possibilities.

"5. You are requested to advise the Board definitely upon the cost of constructing, maintaining and operating an aqueduct along the route recommended by you.

"6. You are requested to advise the Board upon the problem of water storage at the western end of the aqueduct. The Board requests in particular your advice as to how much capacity is required for safe regulation and reserve storage; how much of this capacity should be made available in the initial development of the aqueduct, and how much at a later time.

"To assist you in your task, the Board places at your disposal all of the engineering data and facilities of the District, and whatever additional expert advice may be essential to a proper report on the problem.

"Yours very truly,

"THE BOARD OF DIRECTORS OF
THE METROPOLITAN WATER DISTRICT
OF SOUTHERN CALIFORNIA

"By (Signed) W. P. WHITSETT
"W. P. Whitsett, Chairman"

Mr. W. P. Whitsett. December 19, 1930.

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THE METROPOLITAN WATER DISTRICT

OF SOUTHERN CALIFORNIA

"By (Signed) W. P. WHITSETT

"W. P. Whitsett, Chairman"

Mr. W. P. Whitsett. December 19, 1930.

Responding to the requests and instructions contained in the letter of instructions we have the honor to present the following report. This report is accompanied by a number of appendicies in which the major subjects are discussed each under its own heading. There is also a map showing the main features of the principal routes.

The Report of Chief Engineer Weymouth.

Mr. Weymouth's report describes in detail the studies made on each of the routes together with the many variations made on each for the purpose of determining the most favorable location. Geological examinations were also conducted under the direction of Consulting Geologist Dr. F. L. Ransome, who was assisted by Dr. John P. Buwalda, Dr. L. F. Noble, Mr. F. M. Murphy, Mr. Rollin P. Eckis. The results of these studies have been used for the purpose of selecting that route which would encounter the fewest construction difficulties and be the least subject to seismic disturbances.

We find that the investigations recommended in our preliminary report have been carried out by Chief Engineer Weymouth in a most complete and satisfactory manner and that he has given, in the four volumes of his report, a sound basis for reviewing his recommendations and checking the correctness of his conclusions.

The Necessity for an Increased Water Supply.

The increase in the water requirements of the Metropolitan District will follow its population growth as projected from the United States census reports. This increase can be met only by an additional supply from a source outside the District. Such additions to the supply as are now being made by the extension of the Los Angeles Aqueduct and by deeper pumping from the underground basins of the District will meet the increase in demand only for a few years and probably not longer than the period required to bring in a new supply from an outside source.

The Colorado River as a Source of Supply.

With one exception all of the many proposals which have been advanced for augmenting the supply of the

Mr. W. P. Whitsett. December 19, 1930.

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The Colorado River as a Source of Supply.

With one exception all of the many proposals which have been advanced for augmenting the supply of the

District agree that the only practical source for an additional supply is to be found in the waters of the Colorado River. The single exception is the proposal to reclaim the water of the sewage. To some extent this may prove to be possible but none of the water so reclaimed could be used in any municipal system. All of it would necessarily be devoted to manufacturing and irrigation uses.

The flow of the Colorado is ample in volume and, it is our understanding that the District has perfected its right to use 1500 cubic feet per second of this water. The storage volume in the Hoover Reservoir necessary to regulate the flow of the river has also been arranged for by the District under a contract with the United States.

The Aqueduct Routes Considered.

In the order of their location, beginning with the highest on the Colorado River, the routes which we have considered are the following:

1. The San Juan route diverting from the Colorado near the mouth of the San Juan River in Utah. This route would involve the raising of the water by a dam 1080 feet high and the aqueduct would traverse an unsurveyed region in Utah, Nevada and California for a total distance of 850 miles.

2. The Bridge Canyon route would divert from the Colorado at Bridge Canyon about 110 miles by river above the Hoover Dam. From this point the water, after being raised by a dam, would flow by gravity to the District, a distance of 316 miles.

3. The Black Canyon route would divert from the reservoir above the Hoover Dam by a pump lift of 1662 feet. There would be a return power drop of 564 feet and the length of this route would be 300 miles.

4. The Bulls Head route would divert from the Colorado about 50 miles below the Hoover Dam with a pump lift of 2051 feet. The return power drop would be 564 feet. The route would have a total length of 254 miles.

5. The Parker route would divert from the Colorado 150 miles below the Hoover Dam with a pump lift of 1523 feet.

Mr. W. P. Whiteett. December 19, 1930.

District agree that the only practical source for an additional supply is to be found in the waters of the Colorado River. The single exception is the proposal to regulate the water of the sewage. To some extent this may prove to be possible but none of the water so regulated could be used in any municipal system. All of it would necessarily be devoted to manufacturing and irrigation uses.

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The Aqueduct Routes Considered.

In the order of their location, beginning with the highest on the Colorado River, the routes which we have considered are the following:

1. The San Juan route diverting from the Colorado near the mouth of the San Juan River in Utah. This route would involve the reducing of the water by a dam 1000 feet high and the aqueduct would traverse an unsurveyed region in Utah, Nevada and California for a total distance of 850 miles.

2. The Bridge Canyon route would divert from the Colorado at Bridge Canyon about 110 miles by river above the Hoover Dam. From this point the water, after being raised by a dam, would flow by gravity to the District, a distance of 310 miles.

3. The Black Canyon route would divert from the reservoir above the Hoover Dam by a pump lift of 1800 feet. There would be a return power drop of 664 feet and the length of this route would be 300 miles.

4. The Davis Dead route would divert from the Colorado about 80 miles below the Hoover Dam with a pump lift of 2021 feet. The return power drop would be 664 feet. The route would have a total length of 284 miles.

5. The Parker route would divert from the Colorado 150 miles below the Hoover Dam with a pump lift of 1888 feet.

The return power drop would be 252 feet and the route would be 252 miles long.

6. The Picacho route would divert from the Colorado 275 miles below the Hoover Dam and about 20 miles above Yuma with a total pumping lift of 1997 feet. The return power drop would be 620 feet and the total length 234 miles.

7. The All-American route would divert from the All-American Canal in the Coachella Valley at a point 119 miles from its head on the Colorado. The total pumping lift would be 1888 feet. The return power drop would be 406 feet. Its total length, including that part in the All-American Canal, would be 271 miles.

8. The Southern Sea Level route would divert from the Colorado below Yuma into a desilting basin, the Laguna Salada, in the Republic of Mexico, from whence it would be diverted by a 70 mile tunnel to San Diego and thence along the ocean front to a point near Santa Monica. The friction loss in the aqueduct and the lift from sea level to the various communities of the Metropolitan District would be supplied by pumping. The length of this route is 277 miles.

Summary of Conclusions.

Acting under your instructions to recommend an aqueduct plan which will assure the perpetual delivery of an adequate water supply to the Metropolitan District at the lowest possible cost, all elements of construction and operation costs considered, we have made a careful study of the various aqueduct routes described in the report of Chief Engineer Weymouth and have examined all of the most important points and locations in the field.

We have further given extended consideration and study to all of the alternative routes above listed, and present our conclusions as follows:

1. The proposed supply of 1500 second feet is a correct and conservative forecast of the needs of the future and will cover the requirements up to the year 1980.

2. The water of the Colorado is exceptionally pure and free from contamination. Its sanitary quality is excellent and its mineral content is within the limits of an acceptable

Mr. R. P. Whitsett. December 19, 1930

The return power drop would be 252 feet and the route would be 252 miles long.

6. The Picacho route would divert from the Colorado 275 miles below the Hoover Dam and about 80 miles above Yuma with a total pumping lift of 1327 feet. The return power drop would be 630 feet and the total length 234 miles.

7. The All-American route would divert from the All-American Canal in the Coachella Valley at a point 110 miles from its head on the Colorado. The total pumping lift would be 1888 feet. The return power drop would be 408 feet. Its total length, including that part in the All-American Canal, would be 271 miles.

8. The Southern San Isabel route would divert from the Colorado below Yuma into a dwelling basin, the Laguna Salada, in the Republic of Mexico, from whence it would be diverted by a 70 mile tunnel to San Diego and thence along the ocean front to a point near Santa Monica. The reduction loss in the aqueduct and the lift from sea level to the various communities of the Metropolitan District would be supplied by pumping. The length of this route is 377 miles.

Summary of Conclusions.

Having under your instructions to recommend an adequate plan which will assure the perpetual delivery of an adequate water supply to the Metropolitan District at the lowest possible cost, all elements of construction and operation costs considered, we have made a careful study of the various aqueduct routes described in the report of Chief Engineer Weymouth and have examined all of the most important points and locations in the field.

We have further given extended consideration and study to all of the alternative routes above listed, and present our conclusions as follows:

1. The proposed supply of 1800 second feet is a normal and conservative forecast of the needs of the future and will cover the requirements up to the year 1980.

2. The water of the Colorado is exceptionally pure and free from contamination. Its sanitary quality is excellent and its mineral content is within the limits of an acceptable

supply for domestic use. Its convenience of use for industrial purposes may, as the demands of the future require, be improved through softening processes such as are now in use on other water supplies. The silt content of the Colorado is always high but the water can be clarified either by settling in basins or by mechanical means so as to be of entirely acceptable quality for all purposes. Further discussion on the quality of the water is presented in Appendix I.

3. The salt beds in the Virgin Valley will have no harmful or deleterious effect on the quality of the water stored in the Hoover Reservoir. This matter is discussed in Appendix II.

4. After extended examinations and careful analysis of the so-called gravity and sea level routes, we are clearly of the opinion that they are not practical solutions of the problem before the District. They would be more expensive to construct, to operate, and to maintain. They would be less safe than the Parker Route and hence, would not as effectively serve the best interests of the people. These routes are discussed in detail in Appendices IV, V, and VI, while Appendix III presents some of the general principles affecting the choice between a gravity and a pumped supply.

5. We agree with Chief Engineer Weymouth and concur in his conclusion that the best, the safest, and the most economical location for the aqueduct from the Colorado River is that known as the Parker Route. The geological considerations leading to this conclusion are stated in Appendix VII, while the main reasons and recommendations are presented in Appendix VIII.

6. We have made a careful study and analysis of the cost of constructing, maintaining, and operating an aqueduct along the Parker Route, and have concluded that the cost of constructing this aqueduct and all its appurtenant works will be $199,618,000. Of this total cost the sum of $25,965,000 may be deferred for about 15 years after the aqueduct first goes into service. The construction cost of the first development of the aqueduct including arrangements for the clarification of the water is estimated to be $181,072,000. (Details of these figures are shown in Appendix IX).

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8. We have made a careful study and analysis of the cost of constructing, maintaining, and operating an aqueduct along the Parker Route, and have concluded that the cost of constructing this aqueduct and all its appurtenant works will be $199,618,000. Of this total cost the sum of $38,965,000 may be deferred for about 15 years after the aqueduct first goes into service. The construction cost of the first development of the aqueduct including arrangements for the clarification of the water is estimated to be $181,072,000. (Details of these figures are shown in Appendix IX).

7. The annual cost of maintaining and operating the Parker Route Aqueduct after it is in complete commission and delivering 1500 cubic feet per second will be $6,106,000 per annum. This figure covers all costs and expenses including power for pumping after allowing for the value of the return power. This annual cost, however, does not include either interest on the original investment or the annual payments on account of bond amortization. The interest charges on the complete development will be $9,500,000. (These conclusions are amplified in Appendix IX).

8. We have studied the question of the quantity of terminal storage to be provided and, while an ultimate capacity of from 250,000 to 300,000 acre feet will be required, it is our judgment that, the needs during the first 10 or 15 years after the completion of the aqueduct will be reasonably served by from 75,000 to 125,000 acre feet. We therefore recommend that this quantity of terminal storage be provided and that the dams constructed for this purpose be so designed as to permit of their being raised whenever greater storage volume becomes necessary. We estimate that the cost of providing 100,000 acre feet of terminal storage will be $17,500,000. Our conclusions on this question are stated at greater length in Appendix X.

9. Before contracts for construction can be prepared and made ready for advertisement much work must be done in the way of borings and detailed examinations, surveys, and designs. The estimates which have been made include the cost of this work. It should be begun at the earliest possible date so that active construction operations may be immediately put under way on these parts of the aqueduct which will require the longest time for completion. Only in this way will it be possible to realize the bringing in of the Colorado water within the time of six years which has been estimated.

In submitting this report and concluding our services we individually express our appreciation of the aid and assistance which has been rendered in connection with our duties by the Directors of The

7. The annual cost of maintaining and operating the Parker Mesa Aqueduct after it is in complete commission and delivering 1500 cubic feet per second will be $3,108,000 per annum. This figure covers all costs and expenses including power for pumping after allowing for the value of the return power. This annual cost, however, does not include either interest on the original investment or the annual payments on account of bond amortization. The interest charge on the complete development will be $9,800,000. (These computations are amplified in Appendix IX).

8. We have studied the question of the quantity of terminal storage to be provided and, while an ultimate capacity of from 800,000 to 900,000 acre feet will be required, it is our judgment that, the needs during the first 10 or 15 years after the completion of the aqueduct will be reasonably served by from 75,000 to 125,000 acre feet. We therefore recommend that this quantity of terminal storage be provided and that the dams constructed for this purpose be so designed as to permit of their being raised whenever greater storage volume becomes necessary. We estimate that the cost of providing 100,000 acre feet of terminal storage will be $17,800,000. Our conclusions on this question are stated at greater length in Appendix X.

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Mr. W. P. Whitsett. December 19, 1930.

Metropolitan Water District, by Chief Engineer Weymouth, and by the many members of his staff with whom we have been in contact both in the field and in the office.

Respectfully submitted,

Thaddeus Merriman

A. J. Wiley

Richard R. Lyman

Members of the Board of Review
The Metropolitan Water District
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Mr. R. P. Whitnell. December 19, 1930.

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Respectfully submitted,

Theodore Merriman

A. J. Wiley

Richard H. Lyman

Members of the Board of Review
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APPENDIX I

THE QUALITY OF COLORADO RIVER WATER

The Colorado River drains a great area of sparsely settled country and its waters are unusually free from sewage and industrial pollution. A great proportion of the total flow of this river originates in the upper basin which is so remote that even if there should be pollutions within that area they would be wholly removed during the time of transit through the canyon section of the river. For these reasons the sanitary quality of the Colorado River is, and will always remain, of the very best.

The extensive studies made by the United States Geological Survey since 1925 fully disclose the quality of Colorado River water, both as to the quantity of silt that is transported in a state of suspension, as well as the amount of mineral matter carried in solution.

The silt transported by the Colorado may readily be removed by settlement either with or without the use of mechanical apparatus. The Hoover Reservoir will dispose of all of the silt that enters the Colorado above Black Canyon but the water released from it will again become turbid as it flows onward below that place. In connection with the taking of water from the river at any point below Black Canyon, arrangements must be made to remove the silt which the water will carry. On the Parker route, which we have recommended, this will be accomplished by means of mechanical silt removers in conjunction with sedimentation in the Hayfield Reservoir located near the summit of that route. Still further protection and complete removal of any small remaining amounts will be afforded by the detention of the water in the terminal storage reservoirs. As pointed out in Appendix VIII, it will be possible, at a later time, to construct a dam at the Upper Parker site, thus forming a reservoir basin in which practically all of the silt will be removed and from which clear water can be pumped into the aqueduct.

This matter of silt is a simple one when compared with the difficulties of the project as a whole. It is a problem which is common to all of the routes taking the water from the river below Black Canyon. The best and most efficient sedimentation will be had in the Hoover Reservoir. The Bridge Canyon project would, for a limited period after completion, also furnish settled water, though at times, because

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This matter of silt is a simple one when compared with the difficulties of the project as a whole. It is a problem which is common to all of the routes taking the water from the river below Black Canyon. The best and most efficient sedimentation will be had in the Hoover Reservoir. The Bridge Canyon project would, for a limited period after completion, also furnish settled water, though at times, because

of the relatively small capacity of that reservoir, some trouble with turbidity would probably be had. This is particularly true for a low dam and, even with a high dam (875 feet), would become of the utmost importance as the reservoir fills with silt. It is thus evident that the Bridge Canyon project because of its limited reservoir capacity could not be permanently depended on to furnish clear water. (See Appendix V).

There is no doubt that the silt can be effectively removed from the Colorado water under any one of the plans that have been considered and the cost of the constructions necessary for this purpose have been included in the estimates.

The mineral content of the Colorado water has been determined by the United States Geological Survey at Grand Canyon for the years 1925-1926; 1926-1927 and 1927-1929. The Survey publications also show the mineral content at Topock and Yuma and indicate that the quality of the water is practically the same at all three of these widely separated stations.

Colorado River water is successfully used for municipal purposes at Yuma, Arizona, and at other towns in the Imperial Valley even under the condition of the great seasonal variations which occur. That is to say, the dissolved solids range from over 1000 parts per million in January to less than 300 parts in June. The Black Canyon Reservoir will equalize this great natural variation and the water, under any of the projects diverting from or below that reservoir will contain dissolved solids in the same amount as the yearly average which, for the years of record above referred to, was 528 parts per million.

The great value of the Black Canyon Reservoir in equalizing the mineral content is thus made evident. The Bridge Canyon Reservoir with its total capacity of only 6,240,000 acre feet and its available storage of only 500,000 acre feet could not effectively equalize the flow of the Colorado and, consequently, the water delivered from it would be more variable in its mineral matter than would water from the Black Canyon Reservoir or from any intake below it. This is an important consideration.

The Colorado River water is to be classed as a comparatively hard water from the viewpoint of domestic use. Yet, as has been pointed out it is satisfactorily used at

of the relatively small capacity of that reservoir, some trouble with turbidity would probably be had. This is particularly true for a low dam and, even with a high dam (575 feet), would become of the utmost importance as the reservoir fills with silt. It is thus evident that the Bridge Canyon project because of its limited reservoir capacity could not be permanently depended on to furnish clear water. (See Appendix V).

There is no doubt that the silt can be effectively removed from the Colorado water may one of the plans that have been considered and the cost of the constructions necessary for this purpose have been included in the estimates.

The mineral content of the Colorado water has been determined by the United States Geological Survey at Grand Canyon for the years 1923-1926; 1928-1927 and 1927-1929. The survey publications also show the mineral content at Topock and Yuma and indicate that the quality of the water is practically the same at all three of these widely separated stations.

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The great value of the Black Canyon Reservoir in equalizing the mineral content is thus made evident. The Bridge Canyon Reservoir with its total capacity of only 6,240,000 acre feet and its available storage of only 800,000 acre feet could not effectively equalize the flow of the Colorado and, consequently, the water delivered from it would be more variable in its mineral matter than would water from the Black Canyon Reservoir or from any intake below it. This is an important consideration.

The Colorado River water is to be classed as a comparatively hard water from the viewpoint of domestic use. Yet, as has been pointed out it is satisfactorily used at

Yuma and a number of Imperial Valley towns. Later on as the art of municipal water supply advances and the public demand for softer water increases it can be treated to any reasonable degree that may be desired. The aqueduct location should be so chosen and positioned that a softening plant may be installed at a later time.

Colorado water is now and has been successfully used for purposes of irrigation in the great Imperial Valley. It waters crops of every kind including citrus trees in Arizona. The average boron content has been determined to be 0.18 parts per million at Yuma and this is well within the permissible limit of tolerance even for such crops as lemons and walnuts. Much of the water now used for irrigation in the lower Colorado district contains more than 0.18 parts per million of boron. This is due to the seasonal variations between high and low water flows. The Hoover Reservoir will average out the boron content by reducing its concentration during low flow periods by dilution with the purer waters of the flood flows which now run largely to waste. Thus will the situation be made better than it now is under natural conditions.

It has been said that the flooding of the Virgin Valley will increase the boron content of the water of the Black Canyon Reservoir but no evidence of boron bearing minerals in any material quantity has been adduced. In fact a careful examination for this very purpose showed that there are no boron bearing minerals in the Virgin Valley which would, to any unreasonable extent, cause the quantity of boron in the water to become greater than it now is.

APPENDIX II

SALT DEPOSITS IN THE VIRGIN VALLEY

In our preliminary report of December 21, 1929, we recommended that detailed studies and investigations be made of the salt deposits in the Virgin Valley so that the exact situation and all the facts in regard to them would be available. This recommendation has been carried out and the results of the surveys and geological examinations show that the exposed area of the salt beds is only 1-3/4 acres and that the total area of the salty ground is 6-1/3 acres. This total area is about the same as that of two or three city blocks, or less than five one-thousandths of one per cent of the total surface of the Hoover Reservoir.

We have twice examined and studied these deposits on the ground. Our direct observations and the results of the surveys and geological examinations have convinced us that this salt cannot possibly, under any condition, produce any injurious effect. The volume of the water in the Hoover Reservoir is so great and the quantity of salt in these beds is so small that if all of the salt were suddenly dissolved to a depth of 10 feet the effect would be so slight that it would be absolutely imperceptible. (This of course is an impossible assumption.)

Thus is the problem made simple. It is one which should not cause the slightest concern or apprehension. All of the prophesies as to the effect of these salt beds have been based on fear and apprehension rather than on fact and knowledge. Nevertheless, in spite of what we have said, if there should remain in any mind the slightest doubt, we recommend that these salt beds and the surrounding salty ground be covered with a blanket of clay and earth to a depth of ten feet. The effect of such a blanket will be that of making conditions practically the same as if the salt beds had never existed. The estimated cost of such a covering is about $40,000, and this cost is a measure of the inconsequential nature of the problem which these salt beds present.

APPENDIX III

GRAVITY SOURCES OF SUPPLY

Responding to the particular instruction that we give full consideration to the merits of the possibilities for bringing water into the District by means of gravity flow, we have given careful attention to this phase of the problem and have studied it in detail.

There is a natural and widespread belief that the most satisfactory supply of water is generally to be obtained from a source located at such a height that its waters will flow down to the place of use as impelled by nature. A supply of this kind is, of course, always desirable, yet when, as in the case before us, it becomes necessary to go great distances to find water sufficiently high to flow by gravity, it is then of fundamental importance to consider other possible alternatives and to determine which one of them, all things considered, is the best and the most economical. It is not sufficient to conclude that because a gravity source is desirable that therefore no other supply should be considered. The final determination must be based on all of the facts relating to each particular situation. To this end we have given extended study to the several gravity routes that have been suggested and have carefully weighed the features and possibilities of each including the Southern Sea Level Route.

These routes are considered and discussed in detail in Appendices IV, V and VI.

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These routes are considered and discussed in detail in Appendices IV, V and VI.

APPENDIX IV

THE UPPER COLORADO RIVER OR SAN JUAN PROJECT

This is the gravity supply plan proposed by Captain Jay Turley and is based on water rights alleged to be owned by him in the basin of the San Juan River in New Mexico. It involves the construction of a dam 1080 feet high across the Colorado River at Navajo Mountain in Glen Canyon in the State of Utah thus creating a vast reservoir with a capacity of 106,000,000 acre feet of which only 20,000,000 acre feet would be available for use. From this dam a north side aqueduct and canal 850 miles long, starting at elevation 4250 would lead west through southern Utah and across Nevada, south into California and thence to The Metropolitan Water District and the Coastal plain. The water thus delivered would be employed for the generation of electric power before going into the District and the profiles indicate that an average drop of about 1500 feet might be made available to develop about 250,000 h.p. In connection with this general plan, a second high level canal is also proposed for conveying water to the valley of the Gila River in southern Arizona together with power drops from the north side canal into the Colorado River at Boulder and Black Canyons both in the State of Nevada. From this latter drop a lateral canal in Arizona to supply the district east of Parker is also projected.

This plan looks toward benefiting the States of Utah, Nevada, Arizona and California through, and into which its aqueducts and canals are proposed to extend. It is a gigantic and far flung project and would require not only the active cooperation and financial participation of all these states but also that of many other interests. The acquiescence of New Mexico whose waters are proposed to be taken for use in California would be a sine qua non as, also, would that of the states against which the diversion would be effective. This plan would further require the concurrence of Utah and Colorado in which large areas of land would be flooded by the proposed reservoir.

After careful consideration of all the details of this plan we find that it is entirely impracticable and not susceptible of adoption either in whole or in part. Among our reasons for this conclusion are the following:

APPENDIX IV

THE UPPER COLORADO RIVER OR SAN JUAN PROJECT

FIRST. This project is physically dependent on a rock fill dam 1080 feet high. No dam of this height has ever been built and we believe such a structure to be outside the limits of present day construction practice. The largest rock fill dam now in building on Salt Creek, in California, will have a height of only 330 feet. The largest projected masonry dam (Hoover) will be only 730 feet high above bed rock.

SECOND. There has been no showing that the consents of Utah, Nevada, Arizona, New Mexico and Colorado could be obtained to the invasions of their sovereignties which this project contemplates. It is a paper plan in which no interest has been shown to exist in even a single one of the many states which it affects. Only in Southern California where its proposer, as an individual, would sell the water rights he claims to own, is it being discussed.

THIRD. Even if it be granted that the plan is one which could be developed through the mutual cooperation and interest of the several States as a means for the conservation of the natural resources involved, it must be pointed out that these interests are so varied that many years would be required for harmonizing them. Not until after agreement on the physical details and the apportionment of benefits has been reached could this project be financed. This operation alone, because of its magnitude, would require much time for discussion and determination. The Metropolitan District cannot possibly await the conclusion and agreement on any plan which is so remote and so improbable of accomplishment.

FOURTH. The aqueduct and canal system traversing Utah and Nevada and conveying water to California would be subject to taxation in those states as, also, would the dam in Utah, and the reservoir in Utah and Colorado. This aqueduct system is more than three times as long as that from the Colorado River at Parker and would necessarily be far more than three times as costly to construct, to operate and to maintain.

FIFTH. This project sets at naught the provisions of the Colorado River Compact and would require the complete revision of that document which, after nine years of effort, has not yet been ratified by all of the interested states.

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FIFTH. This project rests at naught the provisions of the Colorado River Compact and would require the completion revision of that document which, after nine years of effort, has not yet been ratified by all of the interested states.

SIXTH. The validity of this project depends absolutely on the huge reservoir which it proposes. The surface area of this great body of water would be 750,000 acres and the annual evaporation loss from it would, at the least, amount to 3,750,000 acre feet or practically one-half of the entire quantity apportioned to the states of the lower basin under the Colorado River Compact. This evaporation loss, moreover, is far greater than the total amount of water alleged to be available under the rights claimed to be owned by the proponent of this project. It would be difficult to conceive of a more wasteful plan. Attention is further called to the fact that this reservoir, because of its great capacity, might require as much as ten years for filling. This project could not furnish water until the reservoir was filled to aqueduct level and ten years of delay on this account is unthinkable.

SEVENTH. The proposer of this project has not shown that his title to the waters of the San Juan Basin is clear. He contends that it is based on certain filings made in the years 1901 to 1905, prior to adoption of the Constitution of the State of New Mexico, and that, therefore, these rights are beyond the control and regulation of the Sovereignty of that State. This is a legal proposition on which we will not express a judgment, yet, as all law is based on reason, we cannot refrain from expressing the conviction that this proposition is basically unsound. The sovereignty of a state may not be set at naught by the simple assertion of an alleged individual right. The power of a state within its domain is omnipotent and transcends all other rights of every kind save only those delegated to the United States by the Federal Constitution.

With respect to the control of its waters by a state the Supreme Court said in Kansas v. Colorado, 206 U. S. 46, 94.

> "---It (the State) may determine for itself whether the common law rule with respect to riparian rights, or that doctrine which obtains in the arid regions of the West of the appropriation of waters for the purposes of irrigation, shall control. Congress cannot enforce either rule upon any State.---"

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Again in U. S. v. Crane, 245 U. S. 216, 219, the Supreme Court said:

"---The States have authority to establish for themselves such rules of property as they may deem expedient with respect to the streams of water within their borders both navigable and non-navigable, and the ownership of the lands forming their beds and banks---".

In any case where private rights conflict with those of the sovereign the position of the latter is defined in the words of Mr. Justice Holmes in Hudson Co. Water Co. v. McCarter, 209 U. S. 349, 356.

"---This public interest is omnipresent wherever there is a State, and grows more pressing as population grows. It is fundamental, and we are of the opinion that the private property of riparian proprietors cannot be supposed to have deeper roots.---"

The power of the State to protect itself and the welfare of its people is unlimited within the realm of its sovereignty as a member of the Union. The Supreme Court in this connection, in New York v. Miln, 11 Peters 102, 139, said:

"---It is not only the right but the bounden and solemn duty of a state to advance the safety, happiness and prosperity of its people, and to provide for its general welfare by any and every act of legislation which it may deem conducive to these ends.---"

To contend, therefore, as the proposer of this plan does, that his rights, if any there be, are beyond the law and the jurisdiction of the Sovereignty of New Mexico is to advance the impossible.

EIGHTH. Even if these alleged water rights in New Mexico are valid actualities, the exercise of them in the manner proposed under this plan cannot possibly make them effective within the domains of Utah, Arizona and Nevada.

NINTH. The State Engineer of New Mexico in his Eighth Biennial Report (1926-1928) in regard to the water rights in question, says:

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"---It is the opinion of this office that any rights claimed under Declaration No. 0-210 have been forfeited as the declarant has failed to state that beneficial use of the water has been made.---"

How, possibly, could The Metropolitan Water District engage in an enterprise on the basis of alleged rights as to which the responsible official of the State, where they are located, says that they have been forfeited?

TENTH. The cost of an aqueduct for delivering 1500 cubic feet per second of water to the Metropolitan District under this plan would undoubtedly approximate $1,000,000,000. This aqueduct moreover, without the dam as proposed, would be worthless. We have been unable to estimate the cost of this dam, because, as already stated, we believe it to be outside the possibilities of current construction practice. The Metropolitan District cannot engage on any project involving so great an expenditure as that indicated for this aqueduct alone, nor can it embark on any undertaking which has for its keystone a dam which, under present day engineering practice, cannot be built.

Summing up the foregoing it appears that this project is entirely beyond the possibility of realization. It is many times more costly than any of the other plans that have been considered. In fact, the annual interest charge on the cost of the aqueduct alone at 4-3/4 per cent would be $47,500,000. This interest money would, in only five years, completely pay all of the construction cost on the Parker route which we have recommended for adoption. It is our judgment, therefore, that this San Juan River project should be eliminated from consideration.

APPENDIX V

THE BRIDGE CANYON GRAVITY PROJECT

This project is the one proposed by Mr. E. C. LaRue. It has been extensively investigated and the engineering staff of the District has made detailed surveys of the proposed dam site and of all of the country covered by the possible aqueduct routes from Bridge Canyon. Geologists Dr. F. L. Ransome, Dr. L. F. Noble, Mr. F. M. Murphy and Mr. Rollin P. Eckis have examined and reported on the geological conditions at the dam location and along the aqueduct routes. We have visited the dam site and have studied all of the above reports together with the details of the plans and estimates of cost that have been made and find that every factor necessary to a complete analysis and understanding of this project is available. All of these matters have passed under our review.

Any aqueduct from Bridge Canyon must cross the Colorado River and there are, in general, only two practicable points where such crossing can be made, namely at Topock and at Bulls Head. Both of these crossing routes have been examined and analyzed by the engineers of the District. The most desirable and most economical of them is that which crosses the Colorado at Topock and this is the one which has been used in the comparative studies.

An examination of the map showing the several possible aqueduct locations makes it evident, if the Bridge Canyon line were routed via Bulls Head, that it would be substantially shortened. If so located, however, such a line would have to be built as a tunnel for a greater proportion of its length. This is true because of the higher land through which the aqueduct would thus be caused to pass west of the Colorado River. It is also true because in the location of an aqueduct the route followed depends much more importantly on the height of the ground than it does on its simple position on a flat map. An aqueduct is not like a highway which can be made to pass uphill and down almost at will. An aqueduct is held to a rigid slope much more so than a railroad which, in turn, is far less flexible than a highway. A gravity flow aqueduct has only a limited choice of routes because it must start and end at fixed heights. On the other hand the location of an aqueduct conveying pumped water may be greatly varied and is therefore susceptible of being routed along better and more economical lines.

Should the Bridge Canyon route cross the Colorado at Bulls Head the longer lengths of tunnel west of the

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An examination of the map showing the several possible aqueduct locations makes it evident, if the Bridge Canyon line were routed via Parker Dam, that it would be substantially shortened. If so located, however, much a line would have to be built as a tunnel for a greater proportion of its length. This is true because of the higher land through which the aqueduct would thus be caused to pass west of the Colorado River. It is also true because in the location of an aqueduct the route followed depends much more importantly on the height of the ground than it does on its position on a flat map. An aqueduct is not like a highway which can be made to pass readily and down almost at will. An aqueduct is held to a quite close grade much more so than a railroad which, in turn, is far less flexible than a highway. A gravity flow aqueduct has only a limited choice of routes because it must start and end at fixed heights. On the other hand the location of an aqueduct conveying pumped water may be greatly varied and is therefore susceptible of being routed close better and more economical lines.

Should the Bridge Canyon route cross the Colorado at Boulder Basin the longer lengths of tunnel west of the

Colorado could be avoided only by pumping to a higher level. If the water were pumped near Bulls Head through a height of about 1000 feet the aqueduct could then follow along the Black Canyon route. (See Map accompanying this report). In such a case, however, the Bridge Canyon route would become a pumping line and all of its gravity features would disappear.

The location of the Bridge Canyon aqueduct laid down by the engineers of the District is clearly as good a line as can be located with a dam 600 feet high. If the grade of this aqueduct should be flattened the depths of the construction shafts along the tunnels would be somewhat reduced but, as the slope is made less, the aqueduct for its entire length would have to be made larger in order to carry the same quantity of water. Such increase in size would far more than offset the comparatively small saving in cost that would result from making the shafts relatively less deep.

In regard to the geological factors which must be considered along the line of the Bridge Canyon route, it is to be pointed out that unless greatly lengthened this line must pass under the deep wash filled valleys in Arizona where much difficult tunnelling conditions are likely to be encountered. Similarly it must pass under the Lucerne Valley and, moreover, it must cross the San Andreas fault near San Bernardino in tunnel deep below the ground where serious construction conditions would undoubtedly be met, and where the later safety of the tunnel against earth movement would be a minimum. In our study of this line and in the estimates of its cost, which have been made, no complete allowance for these untoward geological features has been included. While these conditions present serious obstacles to the successful execution of this Bridge Canyon aqueduct, and while they cannot be entirely avoided by any practicable change in location, yet, for the purposes of this discussion, and in order to view this project in its most favorable light we have assumed them to be non-existent. In other words we have considered that the geological conditions along the Bridge Canyon route are as good as along the best of all the routes which have been studied. (As a matter of fact, however, the deep tunnel crossing of the San Andreas fault which this gravity route cannot in any way avoid, is alone sufficient to rule it out from consideration).

The estimate of cost on the Bridge Canyon route is predicated on a dam 600 feet high including an allowance of $11,000,000 to cover the expense of providing auxiliary storage capacity in the upper basin of the Colorado for the purpose of regulating the supply. The cost for this route

complete is $467,928,000 and this is the least expensive of three Bridge Canyon gravity route locations which were analyzed and estimated in detail with heights of dam at 600 and 900 feet. This cost of $467,928,000 compares with the cost of the Parker route complete of $199,618,000, (Appendix IX), and the saving in favor of the latter is $268,310,000.

While the Bridge Canyon project would deliver water into the District by gravity without the direct expenditure of power it would, nevertheless, consume the power which the Bridge Canyon dam would create in lifting the water up to the aqueduct through which it would flow by gravity. That is to say, if the water were not taken out of this reservoir into the aqueduct it would develop power that could be used elsewhere. This is exactly what happens on every aqueduct route where power is expended that might be put to other use. The diversion of water from the Bridge Canyon Reservoir will not only reduce the output of the power plant there proposed to be located, but it will also reduce the output at Black Canyon. The total annual loss of power so caused (with an 875 ft. dam) will be 1,230,000,000 kilowatt hours. This quantity of power will be expended in conveying water to the District just as surely as if an equal amount were used for pumping. The fact of the matter is that it is never possible, at any place, to have both the water itself as well as the power it contains.

On the pumping routes the water is lifted with pumps driven by electric power while on the Bridge Canyon project it is lifted by dollars through the agency of a dam costing $88,183,000, which raises the water up to the height from which it will flow by gravity into the District. The net result in both cases is the same. The lifting of the water costs money and that route which is the least expensive to construct and to maintain is the best.

Hydroelectric power is produced by falling water. If no water falls no power is generated and if the quantity falling is reduced the power output will be correspondingly diminished. The advocates of the gravity routes have overlooked this elementary consideration. The essence of the problem is always that of determining which route or plan, all things considered, will be the most economical and will best serve the interests of the Metropolitan District.

Analyzing the situation further, it appears that in order to develop the Bridge Canyon project it would be necessary to make an initial investment of $467,928,000 or $268,310,000 more than that required to construct the Parker (Colton) route. In connection with the operation of the Parker route

the total yearly quantity of power required for pumping will be 2,383,600,000 kw.-hr., while the power plant at the Parker dam and the return drop will, in the aggregate, produce 553,099,000 kw.-hr. leaving 1,830,501,000 kw.-hr. as the amount of power needed to be secured from outside sources for the operation of this route.

The Bridge Canyon project (with an 875 ft. dam) by taking the water out of its own reservoir will cause to itself and to the power plant at Black Canyon a yearly loss of 1,230,000,000 kw.-hr., which is 70% of the power required to be obtained from outside sources for all of the pumping necessary under the Parker plan. Casting up the accounts it thus appears that the annual saving in power between the two plans is:

1,830,501,000 kw.-hr.	needed under the Parker project
1,230,000,000 kw.-hr.	lost under the Bridge Canyon plan
600,501,000 kw.-hr.	Bridge Canyon saves over Parker

In addition to the above saving the Bridge Canyon project will also generate a further quantity of 1,744,817,000 kw.-hr. per year, and its aggregate net beneficial power effect would be as follows:

600,501,000 kw.-hr.	Bridge Canyon saves over Parker
1,744,817,000 kw.-hr.	generated at Bridge Canyon
2,345,318,000 kw.-hr.	Total beneficial effect of Bridge Canyon project at place of generation.

In order to secure this beneficial effect, the Bridge Canyon plan would construct a dam across the Colorado River and a length of 50 miles of aqueduct more than the Parker route. The cost of these constructions would be at least $130,000,000. On this sum the annual interest charge including taxes but without the cost of depreciation, of operation and maintenance or of amortization, would be $11,000,000, and the unit interest cost of each kilowatt-hour of beneficial effect at the point of generation would be 4.70 mills as compared with the price of 1.63 mills at which an equivalent quantity of energy could be purchased at Black Canyon. The power thus beneficially saved plus that made available by the Bridge Canyon gravity project is clearly outside the realm of economic possibility.

Even from the point of view of saving power for the general use and prosperity of all the South Western States the Bridge Canyon project is without merit. The water it

the total yearly quantity of power required for pumping will be 2,383,800,000 kw.-hr., while the power plant at the Parker dam and the return drop will, in the aggregate, produce 553,098,000 kw.-hr. leaving 1,830,801,000 kw.-hr. as the amount of power needed to be secured from outside sources for the operation of this route.

The Bridge Canyon project (with an 875 ft. dam) by taking the water out of its own reservoir will cause to itself and to the power plant at Black Canyon a yearly loss of 1,230,000,000 Kw.-hr., which is 70% of the power required to be obtained from outside sources for all of the pumping necessary under the Parker plan. Casting up the accounts it thus appears that the annual saving in power between the two plans is:

1,830,801,000 kw.-hr. needed under the Parker project
1,230,000,000 Kw.-hr. lost under the Bridge Canyon plan
600,801,000 kw.-hr. Bridge Canyon saves over Parker

In addition to the above saving the Bridge Canyon project will also generate a further quantity of 1,744,817,000 kw.-hr. per year, and its aggregate net beneficial power effect would be as follows:

600,801,000 kw.-hr. Bridge Canyon saves over Parker
1,744,817,000 Kw.-hr. generated at Bridge Canyon
2,345,318,000 kw.-hr. Total beneficial effect of Bridge Canyon project at place of generation.

In order to secure this beneficial effect, the Bridge Canyon plan would construct a dam across the Colorado River and a length of 50 miles of aqueduct more than the Parker route. The cost of these constructions would be at least $130,000,000. On this sum the annual interest charge including taxes but without the cost of depreciation, of operation and maintenance or of amortization, would be $11,000,000, and the unit interest cost of each kilowatt-hour of beneficial effect at the point of generation would be 4.70 mills as compared with the price of 1.63 mills at which an equivalent quantity of energy could be purchased at Black Canyon. The power thus beneficially saved plus that made available by the Bridge Canyon gravity project is clearly outside the realm of economic possibility.

Even from the point of view of saving power for the general use and prosperity of all the South Western States the Bridge Canyon project is without merit. The water it

proposes to use is interchangeable with power, yet to the Coastal Plain of California water is worth inconceivably more than power. Water is an absolute and primary necessity. Power is a useful and desirable convenience which can be produced from other sources and at far less cost than in combination with a "gravity" flow aqueduct.

The Bridge Canyon plan would be far sounder if it were predicated on pumping the water directly out of the Colorado at Parker with power produced at Bridge Canyon and without assuming the burden of the cost of the additional 50 miles of aqueduct which it proposes. The water will naturally flow down the Colorado River from Bridge Canyon to Parker more cheaply than through any aqueduct that can be built. A plan such as this would be a self-contained plan and would bring about the production of power which would not otherwise be likely to be soon developed. A set-up of this kind would furnish all of the energy necessary for pumping on the Parker route and would further make available a surplus for other purposes. It would not reduce either its own power output or that at Black Canyon and would moreover be much less costly. With power available at Black Canyon at 1.63 mills per kw.-hr. the need for a Bridge Canyon power development is, however, far from being apparent.

Our instructions require that we fully discuss all of the gravity routes which have been proposed. What we have already said of the Bridge Canyon project, in our judgment, completely disposes of it as a proposition for meeting the needs and requirements of the District. But there are still other objections to this plan and to these, among others, we refer as follows:

FIRST. The Bridge Canyon project could not in the interest of the people of the District, be undertaken until after the consummation of an agreement with the State of Arizona. The dam and reservoir, together with 105 miles of aqueduct, would be located in that State. The total value of those structures would be close to $200,000,000, and this value would undoubtedly be taxable. Without an agreement as to this feature it is conceivable that the annual tax bill might exceed $5,000,000, or much more than the entire value of the total beneficial power effect which the project might have.

The attitude of Arizona in regard to this matter of taxation is well stated in paragraphs X and XI of the Bill of Complaint of that State in its recently instituted

suit before the Supreme Court. Arizona v. the States of California, Nevada, Utah, New Mexico, Colorado, Wyoming, and Ray Lyman Wilbur Secretary of the Interior (October Term 1930). Paragraph XI of the Complaint, in referring to the matter of storing water and using dam sites in Arizona, states:

> "Said business and property used in connection therewith would be subject to taxation and would yield substantial revenues to the State of Arizona".

SECOND. In like manner the fundamental interests of Arizona in the waters of the Colorado should be considered and agreement as to them reached before the District commits itself to the development of any resources in that State.

THIRD. As already pointed out the investment in the Bridge Canyon project would be $268,310,000, greater than the corresponding investment in the Parker route. This feature speaks for itself. Even if the estimate of total cost presented by the proposer of this plan, namely, $296,000,000, could be accepted, the initial investment would still be $96,382,000 greater than that for the Parker route. The interest charge on this sum alone would be close to $4,500,000, a sum much greater than the annual cost of the power needed to operate the Parker route. The proposer's estimate of $296,000,000, however, is far too low and could never, by any possibility, be realized. (See Paragraph TENTH hereafter).

FOURTH. The cost of the Bridge Canyon project has been estimated on the basis of a 600 foot dam. Such a plan, however, for the reasons pointed out in Paragraph EIGHTH is not a practical working proposition. If this project is to be made at all useful a much higher dam would be necessary and the proposer has suggested a dam rising 875 feet above the estimated position of the rock bottom. The highest masonry dam yet projected, that at Black Canyon, will be only 730 feet above bedrock, and will be constructed so as to be of the greatest permanence and durability, yet the proposer of the Bridge Canyon dam would boldly go to a height of 875 feet with a thin arch structure. We regard such a design as infeasible and beyond the range of sound engineering practice. It is also to be pointed out that before any dam at Bridge Canyon can be built, the plans would require not only the approval as to safety by the authorities of Arizona, Nevada and California, but also, the sanction of the Federal Water Power Commission.

FIFTH. No right to acquire water for beneficial use can be secured in Arizona without the approval of the Arizona State Water Commission nor can any use be made of water for power development within that State, to exceed 25,000 horsepower, without the express authorization of the Legislature. No dam higher than 15 feet may be built in Arizona unless the plans therefor have been approved by the State Engineer who must further approve the use to which the water is to be put. (Arizona Statutes Revised Code of 1928. Sections 3280-3286 and Session Laws 1929, Chapter 102, Sections 1 and 3).

Only through the agency of an Arizona incorporation could the Metropolitan District secure the rights necessary to proceed with the Bridge Canyon project and surely such rights could not be acquired except at a cost which none of the estimates include. Still further, the transfer of the point of diversion under the rights of the District at Parker, from that place to Bridge Canyon, would affect the power output at the Hoover Dam exactly as if the diversion were made from that reservoir itself. Such right of changing the point of diversion could not be secured except by the payment to the United States of the value of the power that would thus be destroyed at the Hoover Dam.

SIXTH. The difference between the first costs of the Bridge Canyon and the Parker projects is $268,310,000, a sum more than sufficient to purchase the Black Canyon dam and reservoir and power plant which structures will cost the United States only about $108,000,000. This would be a much more economical way of getting power for pumping than by going to Bridge Canyon, though the inevitable tax bills in Nevada and Arizona, if the Black Canyon dam and reservoir were owned by the District, would eat heavily into the profits which the power output would make available.

SEVENTH. The gross return from the sale of power generated by an 875 foot dam at Bridge Canyon is estimated at $3,028,000, a sum much less than the amount of the probable taxes that undoubtedly would be levied on the dam and aqueduct in Arizona. (See Paragraph FIRST). This showing alone indicates that, from the very beginning, the development of power at Bridge Canyon could not carry the greater cost of the aqueduct from that place. As a power development project, pure and simple, a dam at Bridge Canyon would be in a far better way of earning the interest on its cost. In connection with a water supply system and the necessary costly aqueduct, it would always be a losing proposition.

EIGHTH. The limited reservoir capacity of a low 575 foot dam (1,550,000 acre feet), at Bridge Canyon, rules it out from consideration as a practical working proposition. The reservoir formed by such a dam would, within about ten years, have its capacity so reduced by silt accumulations as to destroy its usefulness. A higher (875) foot dam with a total storage capacity of 6,240,000 acre feet would, unless now unforeseen storage developments are made in the upper basin of the Colorado, undoubtedly also be silted full before the bonds issued for its construction were paid off. It would then become necessary to provide other storage higher up on the Colorado and a large part of the original investment at Bridge Canyon would become useless and obsolete. Moreover, the silt laden waters would directly enter the aqueduct and a clarification plant would have to be provided.

NINTH. Even a high dam of 875 feet at Bridge Canyon would render available a usable storage volume of only 300,000 acre feet for regulating purposes. This is too small to safely insure the supply to the District during low water seasons and would utterly fail to regulate the flow for the power development capacity proposed. The water supply of the Metropolitan District must, at all times, be able to meet every demand and particularly during the drier periods when water is most needed. The Bridge Canyon project does not measure up to this important criterion. Any water supply that fails in time of need is a supply only in name.

TENTH. The proposer of the Bridge Canyon project has presented an estimate of cost for its complete construction of $296,000,000, based on an 875 foot dam and with an aqueduct capacity to deliver into the District 1500 cubic feet per second of water. This estimate covers a total length of aqueduct of 360 miles and its cost is placed at $219,000,000. The average cost presented by the proposer is thus seen to be $115 per foot. This is a figure so low as to be obviously impossible of attainment. No one having knowledge of construction costs could give credence to so low an estimate. The proposer of this plan has cited the Shandaken Tunnel of the New York City Water Supply as an indication of the cost of such work but that tunnel, which cost $125 per foot, was very much smaller than the proposed Bridge Canyon aqueduct must be in order to carry 1500 cubic feet per second. A fair average cost per foot for an aqueduct such as that which has here been proposed is $200 per foot or practically double the estimate of the proposer.

ELEVENTH. Under this project as proposed it is further stated that 2,200,000,000 kw.-hr. of electric energy would be delivered for use in the District. This, it is said, would be accomplished by the installation of a generating capacity of 482,000 horsepower at Bridge Canyon and the construction of a transmission line from that place to and into the Metropolitan District. In order to develop and deliver such a quantity of power the plant proposed would have to be operated on a load factor of 84 per cent. Such an extreme result is never obtainable in practice. We have estimated that an installation as proposed, after making proper allowance for losses in transmission, would, under probable working conditions, deliver to the district not more than 1,400,000,000 kw.-hr. In this connection we would point out, as indicated in paragraph EIGHTH hereof, that the available and usable storage of 300,000 acre feet proposed under this plan is inadequate to completely regulate the flow of the river. To secure the power output above indicated additional storage would have to be provided higher up on the Colorado, and the cost of this project would be further increased if the quantity of power suggested by the proposer were to be realized.

TWELFTH. The Bridge Canyon aqueduct as proposed must cross either over or under the Colorado River at or below Topock. No crossing of the river north of that point is practically feasible unless the length of the tunnels be greatly increased or unless a pump lift be introduced. This, of course, would destroy the "gravity" feature of the plan.

THIRTEENTH. To cross the Colorado River with any aqueduct would be a difficult and expensive operation. To cross by means of a bridge might invite the attacks of public enemies and jeopardize the safety of the entire system. To cross under the river by means of a pressure tunnel involves problems and difficulties of the gravest nature. The proposer of this plan has referred to the Hudson River crossing of the New York Catskill aqueduct and indicated that the conditions there are the same as those at his Colorado River crossing. Nothing could be further from the fact. One of us was engaged on the design and construction of that Hudson River tunnel. The head on that tunnel above the river surface is less than 450 feet and not "more than 1500 feet" as stated by the proposer of the Bridge Canyon plan. His own figure for the head at the Colorado crossing is 1300 feet or practically three times that at the Hudson River. The difficulties at

ELEVENTH. Under this project as proposed it is further stated that 2,800,000,000 kw.-hr. of electric energy would be delivered for use in the District. This, it is said, would be accomplished by the installation of a generating capacity of 488,000 horsepower at Bridge Canyon and the construction of a transmission line from that place to and into the Metropolitan District. In order to develop and deliver such a quantity of power the plant proposed would have to be operated on a load factor of 66 per cent. Such an extreme result is never obtainable in practice. We have estimated that an installation as proposed, after making proper allowance for losses in transmission, would, under probable working conditions, deliver to the district not more than 1,600,000,000 kw.-hr. In this connection we would point out, as indicated in paragraph ELEVEN hereof, that the available and usable storage of 800,000 acre feet proposed under this plan is inadequate to completely regulate the flow of the river. To secure the power output above indicated additional storage would have to be provided higher up on the Colorado, and the cost of this project would be further increased if the quantity of power suggested by the proposer were to be realized.

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the Colorado crossing are exceedingly great for a pressure tunnel crossing. At the very least they are three times as difficult as those at the Hudson River which has been incorrectly held up as a prototype.

FOURTEENTH. The estimates of cost made on the Bridge Canyon project as well as those of all the other routes, which have been studied by the engineers of the District, are on a strictly comparable basis. The differences between them therefore disclose the true relative costs. The estimate for this project presented by its proposer is on an unknown basis and one which can never be even approximately realized. If it be said that the estimates of the engineers of the District are too high on the Bridge Canyon route then they are also too high on all of the other routes. If further, it be said that the engineers have estimated the cost of the Bridge Canyon dam at too large a figure then it may be said that even if the Bridge Canyon dam and power plant could be constructed without any expense whatever that the cost of the rest of the project would still be entirely prohibitive.

In view of the foregoing, it is our decided opinion that the Bridge Canyon gravity supply project presents not a single feature of value to the Metropolitan District. It is more expensive and more costly than any of the pumping routes; it traverses the most difficult geological terrain; it presents no offsetting benefit of any kind, and is, from every point of view, clearly outside the realm of practical realization. We therefore recommend that this project be not considered further.

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APPENDIX VI

THE SOUTHERN SEA LEVEL PROJECT

We have considered the possibility of bringing Colorado River water to the Metropolitan District along the general lines of a project proposed by Mr. J. C. Allison. Detailed study of this project showed that a number of corrections would be necessary to make it possible of discussion as well as to improve the location of the aqueduct line proposed. For instance, the Colorado River does not "---brush the eastern slope of the Cocopah Range of mountains---" but is, in fact, miles distant from them. All of this area is in the Colorado Delta where the river wanders at will, and to secure the height necessary for carrying the water into Laguna Salada as proposed it would be necessary to make the diversion from the river in the vicinity of the Pescadero Cut. Again, instead of following the coast line all the way, as proposed, a much better aqueduct location is to be found for the last 60 miles north from the vicinity of San Juan Capistrano. The description which follows is based on these modifications and improvements.

Under this plan the water would be taken out of the Colorado River near the Pescadero Cut within the Republic of Mexico at a place about 20 miles south of the International Boundary. From this point of diversion the water would pass 30 miles through a canal and tunnel having a capacity of 20,000 cubic feet per second into Laguna Salada, a basin-like depression in the Colorado Delta, which, by means of dykes, would be made to serve as a reservoir 40 miles long and 10 miles wide. At a point 67 miles from the Colorado River the water would then be pumped from the Laguna Salada Basin to a height of 230 feet and would pass in deep tunnel 75 miles to a point near San Diego. From here the proposed aqueduct would follow northwesterly along the coast line to near Santa Monica, a further distance of 135 miles. The entire length over which the water would be carried along this route is 277 miles. Of this total 124 miles would be in tunnel, 86 miles in closed conduit or pipe and the remainder, 62 miles, in open canal and in the Laguna Salada. There would be 6 low lift pumping stations along the route north from San Diego. From various points along this aqueduct the water would then be pumped up to the places of use within the District.

After careful study of the features of this proposal, we are of the opinion that it does not constitute a solution of the problem before the District. As a practical plan it is absolutely without merit. Among the reasons which have led us to this conclusion are the following:

FIRST. The intake, the reservoir and all the works

APPENDIX VI

THE SOUTHERN NEW LEVEL PROJECT

We have considered the possibility of bringing Colorado River water to the Metropolitan District along the general lines of a project proposed by Mr. T. G. Allison. Detailed study of this project showed that a number of controversies would be necessary to make it possible of discussion as well as to improve the location of the aqueduct line proposed. For instance, the Colorado River does not "--break the eastern slope of the Canopah Range of mountains--" but is, in fact, miles distant from them. All of this area is in the Colorado Delta where the river wanders at will, and to secure the height necessary for carrying the water into Laguna Salada as proposed it would be necessary to make the diversion from the river in the vicinity of the Pescadero Dam. Again, instead of following the coast line all the way, as proposed, a much better aqueduct location is to be found for the last 60 miles north from the vicinity of San Juan Capistrano. The description which follows is based on these modifications and improvements.

Under this plan the water would be taken out of the Colorado River near the Pescadero Cut within the Republic of Mexico at a place about 20 miles south of the International Boundary. From this point of diversion the water would pass 30 miles through a canal and tunnel having a capacity of 80,000 cubic feet per second into Laguna Salada, a basin-like depression in the Colorado Delta, which, by means of dykes, would be made to serve as a reservoir 60 miles long and 10 miles wide. At a point 87 miles from the Colorado River the water would then be pumped from the Laguna Salada Basin to a height of 250 feet and would pass in deep tunnel 78 miles to a point near San Diego. From here the proposed aqueduct would follow northwesterly along the coast line to near Santa Monica, a further distance of 133 miles. The entire length over which the water would be carried along this route is 277 miles. Of this total 134 miles would be in tunnel, 56 miles in closed conduit or pipe and the remainder, 62 miles, in open canal and in the Laguna Salada. There would be 6 low lift pumping stations along the route north from San Diego. From various points along this aqueduct the water would then be pumped up to the places of use within the District.

After careful study of the features of this proposal, we are of the opinion that it does not constitute a solution of the problem before the District. As a practical plan it is absolutely without merit. Among the reasons which have led us to this conclusion are the following:

FIRST. The intake, the reservoir and all the works

along a distance of 130 miles are on the soil of Mexico. Except by means of an International Treaty the Metropolitan District could not, in any manner known to us, proceed to the development of this project.

SECOND. The proposed canal from the Colorado, into the Laguna Salada, would have a capacity of 20,000 cubic feet per second. It would have to be supported on an embankment gradually increasing in height from the Pescadero Cut to the tunnel entrance at the Cocopah Mountains where it would be fully 35 feet above the supporting ground. The construction and maintenance of such a gigantic canal built of the light silt of the delta, dependent for support upon a spongy and unstable bottom, and subject to attack by the shifting channel of the Colorado is altogether too hazardous a proposition to serve as a vital link in the source of any municipal water supply system. We believe such a channel to be impossible of construction and its proposer has not indicated any means by which it could be done.

THIRD. The tunnel 75 miles long involving shafts up to 3,000 feet in depth and passing through a mountain range, as to which little is known, would be an undertaking at least as difficult and as hazardous as that on any of the long tunnels on the other routes which have been considered.

FOURTH. This plan is proposed to be operated without terminal storage. This could not successfully be done without incurring the daily waste of a large volume of water. The aqueduct from Laguna Salada is 210 miles long and, without storage, could not be operated to meet the daily fluctuations in quantity of use.

FIFTH. The water would be delivered near or at sea level and then would have to be pumped through small mains with the greater attendant losses in friction. It is very doubtful whether any real saving in power consumed for pumping would result from this plan as compared with the Parker Route. Certainly whatever saving might be shown would be more than offset by the greater cost of the project as a whole even if its feasibility could be admitted.

SIXTH. The aqueduct location along the coast line is open to serious objection from the hazard of damage and injury which may result from storms or possible tidal waves. The construction problems along the ocean front and across the many embayments and water courses are also most difficult and present foundation conditions of serious magnitude as well as earthquake

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tunnel entrance at the Cerro Prieto Mountains where it would be
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hazards of important moment.

SEVENTH. All of the intake works and the Laguna Salada storage reservoir are located in a zone of maximum earthquake activity. The San Andreas, the San Jacinto and other faults seem to center directly in the region where the intake works are proposed to be constructed and this entire area is subject to frequent seismic disturbances. This feature alone is sufficient to condemn this project. The high dykes and great earthen structures proposed are all founded on Colorado River silt and would undoubtedly be often seriously shaken and injured. In any such case the entire supply would be jeopardized.

EIGHTH. The proposer of this project states that it would make available 3,000 cubic feet per second of water. We gravely doubt whether even one half of this quantity could be realized. We have estimated the cost of this aqueduct, with no allowance whatever for the proposed elevated canal section on the Colorado Delta (which we believe cannot be built or operated) and without allowance for pumping plants, for transmission lines or for rights of way and concessions in Mexico, to be more than $288,000,000. To bring in as much as 3,000 cubic feet per second as the plan proposes would increase the cost, on the basis above stated, to more than $400,000,000. The estimates of cost presented by the proposer of this plan could never be even approximately realized. Of these estimates he himself says: "The costs suggested herein are, of course, calculated from extremely meager detailed plans---."

While there are many other reasons why this project is both impracticable and undesirable, we will limit this discussion by pointing out only one more objection which is absolutely fundamental and which, of itself, is sufficient to rule this project out from consideration.

NINTH. The Laguna Salada reservoir proposed to be formed would have a surface area of 256,000 acres from which the annual evaporation loss would be 1,920,000 acre feet. This loss is equivalent to that of a continuous flow of 2650 cubic feet per second. This project would thus waste and lose nearly twice as much water as is proposed to be made available over the other routes from the Colorado River. The evaporation of this great quantity of water would so increase the dissolved mineral content of the remainder as to render it absolutely unfit for use.

For the reasons above stated, we recommend that this plan be dismissed from further thought.

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While there are many other reasons why this project is both impracticable and undesirable, we will limit this discussion by pointing out only one more objection which is absolutely fundamental and which, of itself, is sufficient to rule this project out from consideration.

NINTH. The Laguna Salada reservoir proposed to be formed would have a surface area of 528,000 acres from which the annual evaporation loss would be 1,920,000 acre feet. This loss is equivalent to that of a continuous flow of 2650 cubic feet per second. This project would thus waste and lose nearly twice as much water as is proposed to be made available over the other routes from the Colorado River. The evaporation of this great quantity of water would so increase the dissolved mineral contents of the remainder as to render it absolutely unfit for use.

For the reasons above stated, we recommend that this plan be dismissed from further thought.

APPENDIX VII

GEOLOGICAL CONSIDERATIONS

Among the most important of the factors which govern and control the location of an aqueduct are those which have to do with the geology of the territory through which the aqueduct passes. The general considerations under this subject include a wide variety of subjects and conditions. They cover all matters relating to the earth and the rock. They consider the suitability of the materials encountered for the purposes intended. They take account of the structure, permanence and strength of the rocks. They locate the places where ancient earth movements occurred and they disclose the zones within which displacements and faulting are again likely to occur.

Every aqueduct route from the Colorado River to the Metropolitan District must traverse through areas in which the geological conditions vary widely. It is of importance that these conditions should be known, so that the location finally determined upon may avail itself of the best ground and be routed in such manner that all hazardous areas will be avoided as far as possible.

While much was known with respect to the geological conditions before the detailed surveys for the various aqueduct routes were made there was, nevertheless, a large region as to which there was little information and the studies on other areas were far from being complete. The detailed examinations made by the geologists of the District have unfolded and made clear the character of the terrain covered by the various routes and, in arriving at our conclusions, we have been guided by the results of their careful and extensive studies. The following points are to be emphasized.

Fault Crossing.

The Parker Route is clearly the safest of all the routes as against the possibility of earthquake hazard. It crosses all of the active faults in pipe or conduit close to the surface of the ground where access will be easy and where damage resulting from earth movement may be quickly and readily repaired. This route crosses the San Andreas and Mission Creek faults in suitable ground near the head of the Coachella Valley. It crosses the San Jacinto fault system in pipe siphon and, immediately to the west thereof, passes into the heavy, stable granite block in the vicinity of Perris.

APPENDIX VII

GEOLOGICAL CONSIDERATIONS

Among the most important of the factors which govern and control the location of an aqueduct are those which have to do with the geology of the territory through which the aqueduct passes. The general considerations under this subject include a wide variety of subjects and conditions. They cover all matters relating to the earth and the rock. They consider the suitability of the materials encountered for the purposes intended. They take account of the structure, permanence and strength of the rocks. They locate the places where ancient earth movements occurred and they disclose the zones within which displacements and faulting are again likely to occur.

Every aqueduct route from the Colorado River to the Metropolitan District must traverse through areas in which the geological conditions vary widely. It is of importance that these conditions should be known, so that the location finally determined upon may avail itself of the best ground and be routed in such manner that all hazardous areas will be avoided as far as possible.

While much was known with respect to the geological conditions before the detailed surveys for the various aqueduct routes were made there were, nevertheless, a large region as to which there was little information and the studies on other areas were far from being complete. The detailed examinations made by the geologists of the District have unfolded and made clear the character of the terrain covered by the various routes and, in arriving at our conclusions, we have been guided by the results of their careful and extensive studies. The following points are to be emphasized.

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The crossing of these fault systems in this manner and at the places indicated is an entirely safe and satisfactory arrangement. In fact no other or better crossings, in the light of all the information available, seem to be possible.

Quality of Ground Traversed.

The Parker line, elsewhere along its route, is in ground that is safe from earthquake displacements. Southeastward from the crossing of the Mission Creek fault the aqueduct continues in the strong crystalline rocks to and beyond Shaver's Summit. Along this section the rocks are hard and firm. They are parts of the original land mass which has stood throughout the years and shows practically no evidence of movement either recent or since it took on the form which it now retains. East of Shaver's Summit the route passes over open ground and through a number of short tunnels to the Colorado River at Upper Parker. All of this territory is geologically and structurally sound and no trouble from earth movement is to be anticipated.

Between the Coachella and San Jacinto Valleys the Parker Route passes in tunnel through the stable granite rocks forming the westerly end of the San Jacinto mountains. This granite mass has withstood all of the earth movements which have occurred during recent ages and undoubtedly will continue firm and solid in the future.

Lengths of Tunnel.

The longest tunnel on the Parker Route is 13 miles. The maximum shaft depth is 1430 feet and there are only 4 shafts. In these respects the Parker Route is greatly superior to all of the more northerly routes where the tunnels are very much longer. This thirteen mile tunnel, moreover, will everywhere pass through rock that promises to be sound and durable and in which no untoward construction difficulties are likely to be encountered. The tunnels on the Black and Bridge Canyon Routes, on the other hand, are very long and pass at great depths under the San Bernardino Mountains. They must cross the general southeast-northwest fault system and because of their depth may encounter heavy rock and high temperatures. The Bridge Canyon line must pass through the San Andreas fault zone deep below the ground and would undoubtedly meet with construction troubles of the most serious kind.

Proximity to Active Fault Lines.

With respect to its position in relation to the active fault zones the Parker Route is better than either the

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The longest tunnel on the Parker Route is 15 miles. The maximum shaft depth is 1650 feet and there are only 4 shafts. In these respects the Parker Route is greatly superior to all of the more northerly routes where the tunnels are very much longer. This thirteen mile tunnel, moreover, will everywhere pass through rock that promises to be sound and durable and in which no untoward construction difficulties are likely to be encountered. The tunnels on the Black and Bridge Canyon Routes, on the other hand, are very long and pass at great depths under the San Bernardino mountains. They must cross the general southwest-northwest fault system and because of their depth may encounter heavy rock and high temperatures. The Bridge Canyon line must pass through the San Andreas fault zone deep below the ground and would undoubtedly meet with construction troubles of the most serious kind.

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All-American Canal Route or the line from Picacho, both of which routes practically follow along and over the San Andreas fault for many miles. These two routes, moreover, are located largely in unconsolidated material which, because of the nearness of the fault, is likely to be severely shaken even by a moderate earth movement. A rigid aqueduct in material of this kind would be likely to suffer great damage. This possibility was clearly shown by the results of the Japanese earthquake of 1923.

Tunnels under Deep Valleys.

The deep valley systems of Southern California and adjacent territory present obstacles of insuperable difficulty to the driving of deep tunnels. A tunnel from Bridge Canyon would of necessity pass under the Grand Wash and the Red Lake Basin in Arizona. A line from Bridge Canyon to Topock would probably encounter much greater difficulty than one passing on a more southerly location through Kingman. While the depth of these valley fills is not definitely known yet there is every reason to believe that they are at least as deep as the height of the hills now rising above the valley surfaces. Careful study of the situation in the Ivanpah Valley has indicated a probable depth of 10,000 feet.

To drive a tunnel through any such valley fill would not be possible, particularly if, as is usually the case, water is present. To lay out a line which would involve passing through a valley of this kind or even close to its bottom would be to invite a situation which might result in difficulties that could not be overcome. No argument could justify such a location. Fortunately the situation is such that there is no need for locating the aqueduct in any ground that is doubtful.

Conclusions.

The Parker Route from every geological consideration, is clearly the best and safest. It passes through ground where the construction difficulties will not be out of the ordinary and where no unusual hazards are to be anticipated. This route, moreover, will have a maximum of safety against dangers of earthquake disturbances and, in case of actual damage resulting from this cause at the known fault crossings, is so located that repairs can be made in the least possible time.

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APPENDIX VIII

THE PARKER ROUTE RECOMMENDED

Of all the routes which we have studied in detail and which are enumerated at page 5 herein, the Parker route is clearly the most favorable. The main reasons for this conclusion are the following:

FIRST. The Parker route, from the viewpoint of the geology of the country, passes through the best terrain. It involves no unusually long tunnels, the construction hazards are the smallest and its subsequent safety against earthquake damage is the greatest. This conclusion is amplified in Appendix VII.

SECOND. While the Parker route is less expensive in first cost than all of the others except the Picacho and the All-American routes, it shows a smaller operating cost than either of these because of its lower pump lift.

THIRD. The net operating cost per acre foot on the Parker route, after retirement of the bonds, will be lower than that on any of the other routes considered.

FOURTH. The quantity of power required for pumping, over and above that produced, along these three routes, after the complete developments have been made, will be as follows:

Parker Route	1,954,014,000 kilowatt hours
Picacho Route	2,725,171,000 kilowatt hours
All-American Route	2,336,830,000 kilowatt hours

The Parker route will thus be the most economical of operation.

FIFTH. The Parker route is the only one on which it is practicable to provide intermediate storage. The Hayfield reservoir gives to the Parker route an important advantage not enjoyed by any of the others and will bring about the delivery of water of a quality equal to that of the best of any one of the other routes and superior to that of either the Picacho or the All-American Canal routes which are its nearest competitors in point of cost. On the All-American route there is a possibility that intermediate storage might be provided but we regard it impracticable to store water below ocean level in the vicinity of the Salton Sea and

APPENDIX VIII

THE PARKER ROUTE RECONSIDERED

Of all the routes which we have studied in detail and which are enumerated at page 8 herein, the Parker route is clearly the most favorable. The main reasons for this conclusion are the following:

FIRST. The Parker route, from the viewpoint of the geology of the country, passes through the best terrain. It involves no unusually long tunnels, the construction hazards are the smallest and its subsequent safety against earthquake damage is the greatest. This conclusion is amplified in Appendix VII.

SECOND. While the Parker route is long expensive in first cost than all of the others except the Pizarro and the All-American routes, it shows a smaller operating cost than either of these because of its lower pump lift.

THIRD. The net operating cost per acre foot on the Parker route, after retirement of the bonds, will be lower than that on any of the other routes considered.

FOURTH. The quantity of power required for pumping, over and above that produced along these three routes, after the complete developments have been made, will be as follows:

Parker Route	1,984,014,000 kilowatt hours
Pizarro Route	3,728,171,000 kilowatt hours
All-American Route	3,856,830,000 kilowatt hours

The Parker route will thus be the most economical of operation.

FIFTH. The Parker route is the only one on which it is practicable to provide intermediate storage. The Imperial reservoir gives to the Parker route an important advantage not enjoyed by any of the others and will bring about the delivery of water of a quality equal to that of the best of any one of the other routes and superior to that of either the Pizarro or the All-American Canal routes which are its nearest competitors in point of cost. On the All-American route there is a possibility that intermediate storage might be provided but we regard it impracticable to store water below ocean level in the vicinity of the Salton Sea and

immediately over the San Andreas fault system.

SIXTH. The Parker route for its entire length is on the soil of California and no question of taxes or assessments in any other State is involved. Water may be taken directly from the Colorado without interference with the rights of any other State. The Picacho and All-American Canal routes are also in this same category.

In view of the foregoing we concur in the recommendation of Chief Engineer Weymouth that the Parker route be adopted. Every indication and all of the evidence is in favor of this route except only the argument of its slightly greater cost over that of its only competitors, the All-American and Picacho routes. We believe, however, that the Parker route is so far superior to both of these routes in all other respects that there can be no doubt as to the correctness of this decision.

The All-American Canal is planned to be constructed by the United States and will take the water of the Colorado through an open and unlined canal 118 miles long to a point in the Coachella Valley where the District would connect with it. This great length of canal passes through a section of country where cloud-bursts of the greatest severity are to be expected. The terrain is generally unfavorable and the canal in many places will be in deep cuts far below the ground surface. Wind storms will carry much sand into this canal. The All-American Canal is located for practically its entire length in deep valley fill material and much of the aqueduct location on this route would necessarily be in the same kind of ground. This line parallels the San Andreas fault system, and is directly over it for many miles besides crossing it a number of times. We believe that these objections are fundamental and definitely eliminate this route from consideration. Should this route be adopted it would become necessary as a matter of prudence and safety to greatly increase the volume of terminal storage and the cost of this increase would tend to offset the lesser cost of the All-American route.

The objections we have presented against the All-American route do not run to this canal for its intended purpose of irrigation. They are, however, of vital moment on a domestic and municipal supply. There is also the further objection that the District would be the last party served from the canal. In such a situation the District undoubtedly would, at times, meet with trouble in securing its

full quota of water. In other words, the last water taken out of the extreme end of a canal is always subject to the vicissitudes which accumulate along its entire length.

The evaporation and seepage losses from the All-American Canal would also be greater than from the Parker route. A share of these losses would, of course, be deductible from the water available for the uses of the District. The sanitary quality of the water would, moreover, not be improved by its passage through the long canal.

In our judgment the foregoing considerations are conclusive and definitely show that the All-American Canal route is one which would not satisfactorily, safely and efficiently meet the needs and requirements of the District.

The Picacho route from some points of view is a close competitor of the Parker route. On the basis of construction cost it stands about midway between the Parker and the All-American Canal routes, but it passes along the dangerous San Andreas fault system for many miles. Its power consumption, as shown in paragraph Fourth herein, would be nearly 50% more than on the Parker route. There is, therefore, no compelling reason in favor of the Picacho route and, in view of the dangers involved along the San Andreas fault and its greater cost of operation, we have set it aside.

The best aqueduct line from the Colorado River is that along the Parker route and in regard to this project as a whole, we present the following suggestions:

It seems desirable to defer the construction of the Parker dam for several years after the completion and going into service of the Hoover Reservoir. This reservoir will remove all of the silt from the Colorado water at the point where it will be discharged below the dam. This clear water will at once begin to pick up and remove the silt now present in the bed and along the banks of the river and will change and modify the regimen of the stream all the way down to the Laguna dam. If a dam is built at Parker, the reservoir thus formed will catch and accumulate all of the silt removed from the Colorado channel between Boulder Canyon and Parker.

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By deferring the Parker dam until after most of

this silt has passed on down the river the reservoir, when built, will be much better and will much more efficiently perform its future service.

The Hayfield reservoir should be put into commission coincidently with the aqueduct and, in order to secure the greatest flexibility of operation, a by-pass around it should be constructed. In this manner the water may be circulated through this reservoir or not as operating conditions may require, or, the reservoir may be allowed to float on the line.

The Parker route as laid down in Chief Engineer Weymouth's report after emerging on the southwest side of the San Jacinto Mountains parallels the San Jacinto fault system and continues to the terminal storage reservoir at Puddingstone. Among other possibilities the engineers of the District have studied and analyzed possible variations of this line west from the San Jacinto Valley. Of these variations, we believe that the best and safest line for the Parker route will cross the San Jacinto Valley in siphon and continue westerly via the vicinity of Perris to the Puente Hills. Terminal storage possibilities along this route are favorable and the terrain from the viewpoint of stability is the best. We recommend therefore that this variant of the Parker route be adopted.

The deferment of the construction of the Parker dam will involve the necessity of providing means for removing the silt from the water until such time as conditions will permit the building of this dam. The estimates of cost set forth in Appendix IX provide for clarification works which, in any event, it would seem prudent to provide during the first few years after the Parker reservoir is put into service.

The estimates of cost presented in Appendix IX are made to include the variations and deferments herein suggested and the matter of terminal storage facilities is discussed in Appendix X.

Final surveys and borings will indicate that various changes in the location of the line, in the length and position of tunnels and in other similar matters will prove to be advisable. Such changes are always indicated for the purpose of reducing costs as well as for placing

the structure in the best ground as it is disclosed and developed by the examinations. Attention is called to this matter, at this time, in order to emphasize the fact that no definitely final location with respect to all of the details can be determined upon until the results of the detailed borings and surveys are available.

APPENDIX IX

THE COST OF CONSTRUCTION, MAINTENANCE AND OPERATION

We have studied and analyzed the cost figures, the quantity estimates and the details of the constructions which are the foundation of the estimates of cost that have been made on the several routes by the engineers of the District. All of these estimates are based on safe and sound practice. They are conservative and represent as closely as any estimate can be made to do the probable cost of the final constructions.

The figures for the unit costs are based on extended analyses which take into account all elements as affected by the construction conditions along the several routes. The results of these analyses were also tested by comparing them with actual construction costs as revealed by the bid figures on other similar work. We have further analyzed these figures by contrasting them with the cost of work done under our own direct experience. In our judgment the estimates of cost which have been made fairly and accurately disclose not only the true relative construction costs of the several routes but also the actual cost which should be realized when the work is put under way.

Taking into account the variations recommended by us in Appendix VIII as to the location of the Parker aqueduct route near its western end we have made an estimate of the cost of its complete construction and find it to be $199,618,000. The principal items making up this total are the following:

*	Investigations and designs	$ 2,500,000
+	The Parker diversion dam	13,058,000
+	The Aqueduct	146,222,000
+	Pumping and power plants and equipment	37,838,000
		$199,618,000

* This item covers borings, surveys, preliminary designs and preparation of contracts.

\+ These items are the estimated costs of the complete aqueduct with all needed appurtenances

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Taking into account the variations recommended by us in Appendix VIII as to the location of the Parker aqueduct route near its western end we have made an estimate of the cost of its complete construction and find it to be $139,818,000. The principal items making up this total are the following:

+ Investigations and designs	$ 2,800,000
+ The Parker diversion dam	13,088,000
+ The Aqueduct	146,222,000
+ Pumping and power plants and equipment	27,828,000
	$139,818,000

* This item covers borings, surveys, preliminary designs and preparation of contracts.

+ These items are the estimated costs of the complete aqueduct with all needed appurtenances

and equipment to handle and deliver 1500 cubic feet per second into the terminal storage reservoirs.

The above figure is the total cost of the Parker aqueduct complete in all of its parts. The natural order of development, however, will be to defer a portion of the cost of the pumping plants and pressure siphons together with, as recommended in Appendix VIII, the construction of the Parker dam and its appurtenances.

The cost of those parts of the project which may be deferred is as follows:

Pumping and power plants and equipment	$12,907,000
The Parker diversion dam	13,058,000
Total Deferment	$25,965,000

The cost for the first aqueduct development not including the Parker dam, then, is as follows:

Total cost of complete aqueduct development	$199,618,000
Less Deferments	25,965,000
Cost of the first aqueduct developments	$173,653,000

Because of the deferment of the Parker dam and reservoir it will be necessary to clarify the water by means of basins and mechanical apparatus. The cost of the structures necessary for this purpose including the cost of the aqueduct arrangements near the intake end will be $7,419,000. The cost of the first aqueduct development with the Parker dam deferred and with clarification works included is thus seen to be:

Cost of the first aqueduct development	$173,653,000
Add for clarification of water	7,419,000
Complete cost of first aqueduct development	181,072,000

This figure of $181,072,000 is our estimated cost of the construction of the first development of the Parker aqueduct including clarification works. This first development will deliver about 800 cubic feet per second. The complete development including the Parker dam may be accomplished

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The cost of those parts of the project which may be deferred is as follows:

Pumping and power plants and equipment	$18,307,000
The Parker diversion dam	13,088,000
Total Deferment	$25,395,000

The cost for the first aqueduct development not including the Parker dam, then, is as follows:

Total cost of complete aqueduct development	$139,618,000
Less Deferments	25,395,000
Cost of the first aqueduct developments	$114,223,000

Because of the deferment of the Parker dam and reservoir it will be necessary to clarify the water by means of basins and mechanical apparatus. The cost of the structures necessary for this purpose including the cost of the aqueduct arrangements near the intake end will be $7,419,000. The cost of the first aqueduct development with the Parker dam deferred and with clarification works included is thus seen to be:

Cost of the first aqueduct development	$121,642,000
Add for clarification of water	7,419,000
Complete cost of first aqueduct development	$129,061,000

This figure of $121,072,000 is our estimated cost of the construction of the first development of the Parker aqueduct including clarification works. This first development will deliver about 800 cubic feet per second. The complete development including the Parker dam may be accomplished

at a later time by the expenditure of $25,965,000. By deferring the Parker dam for about 15 years from the beginning of the work, for the reasons suggested in Appendix VIII, the cost of the first aqueduct development will be increased, as above shown, by the need of arrangements for clarification of the water, by the amount of $7,419,000. This sum is only about one-third of the interest cost that would accrue on the total deferment of $25,965,000 for 15 years and is, therefore, a sound business proposition. The clarifiers provided will, moreover, be available for later use in removing turbidity from the water of the Parker Reservoir during times when local floods will enter it.

Taking into account the cost of the terminal storage which we have estimated in Appendix X as $17,500,000 the total estimated cost of the first development of the Parker project is seen to be:

Complete cost of first aqueduct development	$181,072,000
Cost of terminal storage	17,500,000
Total cost of first development to deliver 800 cubic feet per second of water with terminal storage of 100,000 acre feet	$198,572,000

This figure represents the amount of the bonds needed to be issued at this time for the Parker route Colorado River Aqueduct. In our judgment this amount is ample for the purposes indicated. Under fair average market and labor conditions, during the construction period, it is to be expected that all of the work will be entirely completed within this amount.

Cost of Operation and Maintenance.

The cost of operation and maintenance including the interest on outstanding bonds will vary from year to year. During the construction period the annual interest payments will be constantly increasing until all of the bonds have been issued. This interest cost computed at 4-3/4 per cent on $200,000,000 will be $9,500,000 and this will be a constant annual expense until reduced by bond amortizations as they may be made from time to time.

at a later time by the expenditure of $25,965,000. By deferring the Parker dam for about 15 years from the beginning of the work, for the reasons suggested in Appendix VIII, the cost of the first aqueduct development will be increased, as above shown, by the need of arrangements for clarification of the water, by the amount of $7,415,000. This sum is only about one-third of the interest cost that would accrue on the total deferment of $25,965,000 for 15 years and is, therefore, a sound business proposition. The clarifiers provided will, moreover, be available for later use in removing turbidity from the water of the Parker Reservoir during times when local floods will enter it.

Taking into account the cost of the terminal storage which we have estimated in Appendix X as $17,300,000 the total estimated cost of the first development of the Parker project is seen to be:

Complete cost of first aqueduct development $181,072,000
Cost of terminal storage 17,300,000

Total cost of first development to deliver 800 cubic feet per second of water with terminal storage of 100,000 acre feet $198,372,000

This figure represents the amount of the bonds needed to be issued at this time for the Parker route Colorado River Aqueduct. In our judgment this amount is ample for the purposes indicated. Under fair average market and labor conditions, during the construction period, it is to be expected that all of the work will be entirely completed within this amount.

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The cost of taxes and insurance will increase gradually from the beginning of construction and reach a maximum, on the completion of the second development, of about $250,000 per year.

The cost of power for pumping will increase in proportion with the amount of water used. After the entire project has been completed, it is estimated that this cost will be $5,367,000 annually.

The annual charge for the storage of water in the Boulder Canyon reservoir will increase gradually from the beginning and, when the project is in complete operation, will be $272,000.

The annual cost of operation, maintenance, repairs and renewals will also increase gradually as the use of water increases. During the construction period there will be no charge under this item, and when the aqueduct is in full operation it is estimated that the yearly expense on this account will be $2,217,000.

Summing up the above items the annual maximum cost of operating and maintaining the Parker project will be $6,106,000 while the total carrying charges including interest will be $15,606,000; this maximum will not be reached until about the twentieth year after the beginning of construction and possibly not until later. This annual cost, moreover, will be reduced by smaller interest charges as bond retirements are made at intervals.

By the time the annual operation and carrying charges reach the maximum amount of $15,606,000 there will probably be a population of at least 4,000,000 within the limits of the Metropolitan District and the annual cost of the water then delivered into the terminal storage reservoirs will be $3.90 per capita, or practically one cent per day. Even on the basis of the present population the cost per inhabitant would be less than two and one-quarter cents per day.

The cost of taxes and insurance will increase gradually from the beginning of construction and reach a maximum, on the completion of the second development, of about $350,000 per year.

The cost of power for pumping will increase in proportion with the amount of water used. After the entire project has been completed, it is estimated that this cost will be $3,367,000 annually.

The annual charge for the storage of water in the Boulder Canyon reservoir will increase gradually from the beginning and, when the project is in complete operation, will be $272,000.

The annual cost of operation, maintenance, repairs and renewals will also increase gradually as the use of water increases. During the construction period there will be no charge under this item, and when the aqueduct is in full operation it is estimated that the yearly expense on this account will be $3,317,000.

Summing up the above items the annual maximum cost of operating and maintaining the Parker project will be $6,100,000 while the total carrying charges including interest will be $18,000,000; this maximum will not be reached until about the twentieth year after the beginning of construction and possibly not until later. This annual cost, moreover, will be reduced by smaller interest charges as bond retirements are made at intervals.

By the time the annual operation and carrying charges reach the maximum amount of $18,000,000 there will probably be a population of at least 4,000,000 within the limits of the Metropolitan District and the annual cost of the water then delivered into the terminal storage reservoirs will be $3.90 per capita, or practically one cent per day. Even on the basis of the present population the cost per inhabitant would be less than two and one-quarter cents per day.

APPENDIX X

THE QUANTITY AND COST OF TERMINAL STORAGE

The main regulation of the supply will be effected in the Hoover Reservoir which will deliver into the Colorado River a uniform daily quantity of water. This water will then be withdrawn from the river at Parker and pumped into the Hayfield Reservoir from which it will again be pumped to a still higher level before resuming its flow to the District.

Terminal storage located as near as possible to the delivery end of every long aqueduct is a most desirable feature. Such storage not only serves to iron out the difference between the seasonal demands of water and the uniform rate of delivery through the aqueduct, but also enables the aqueduct to be shut down whenever necessary for repair or other purpose. The longer the aqueduct the more important does terminal storage become and this Colorado River system is one of the longest aqueducts ever projected.

Terminal storage, moreover, is even more important on a system used for domestic supply purposes because of its effect in improving the quality of the water delivered for use. The terminal reservoirs serve as final detention basins in which sedimentation and bleaching of the water will take place and in which the water may be treated to meet the many contingences which arise on every water supply system. Still further, terminal storage is a direct insurance against the possibility of interruption along the entire aqueduct system which lies beyond the reservoirs.

The Colorado River Aqueduct will be constructed in a most substantial nature and long interruptions of the delivery of water through it are not to be anticipated. A terminal storage volume equal to 30 days of aqueduct capacity would call for practically 100,000 acre feet and this quantity would reasonably serve all other purposes during the early years of the project. Later on when the use becomes greater more terminal storage will undoubtedly be required but it does not now seem necessary to provide as much as 300,000 acre feet which the estimates of the engineers of the District indicate to be ultimately necessary.

In view of all the considerations which affect this problem it is our judgment that from 75,000 to 125,000 acre feet of terminal storage should be provided as a part of the first

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In view of all the considerations which affect this problem it is our judgment that from 75,000 to 150,000 acre feet of terminal storage should be provided as a part of the first

installation of the aqueduct. Suitable locations for reservoirs of this capacity are to be found in the Puente Hill District and along the aqueduct line west from the San Jacinto Mountains. After careful examination of all the factors affecting this question, it is our judgment that, as nearly as practicable, 100,000 acre feet of storage should be provided.

The cost of storage reservoirs on many sites has been estimated by the engineers of the District. These estimates for the better sites, generally range from $110 to $220 per acre foot. After careful consideration of all these estimates and plans and of the geological examinations which have been made, it is our judgment that 100,000 acre feet of terminal storage can be developed at a total cost of $17,500,000. The unit cost of this storage will be $175 per acre foot on the basis of building the necessary dams so that later on, they may be raised to provide additional storage as future developments require. The storage reservoirs constructed for this first installment of terminal storage should also be located so that they may readily be connected with other reservoirs built for the same purpose and thus become parts of the complete system which the future will require.

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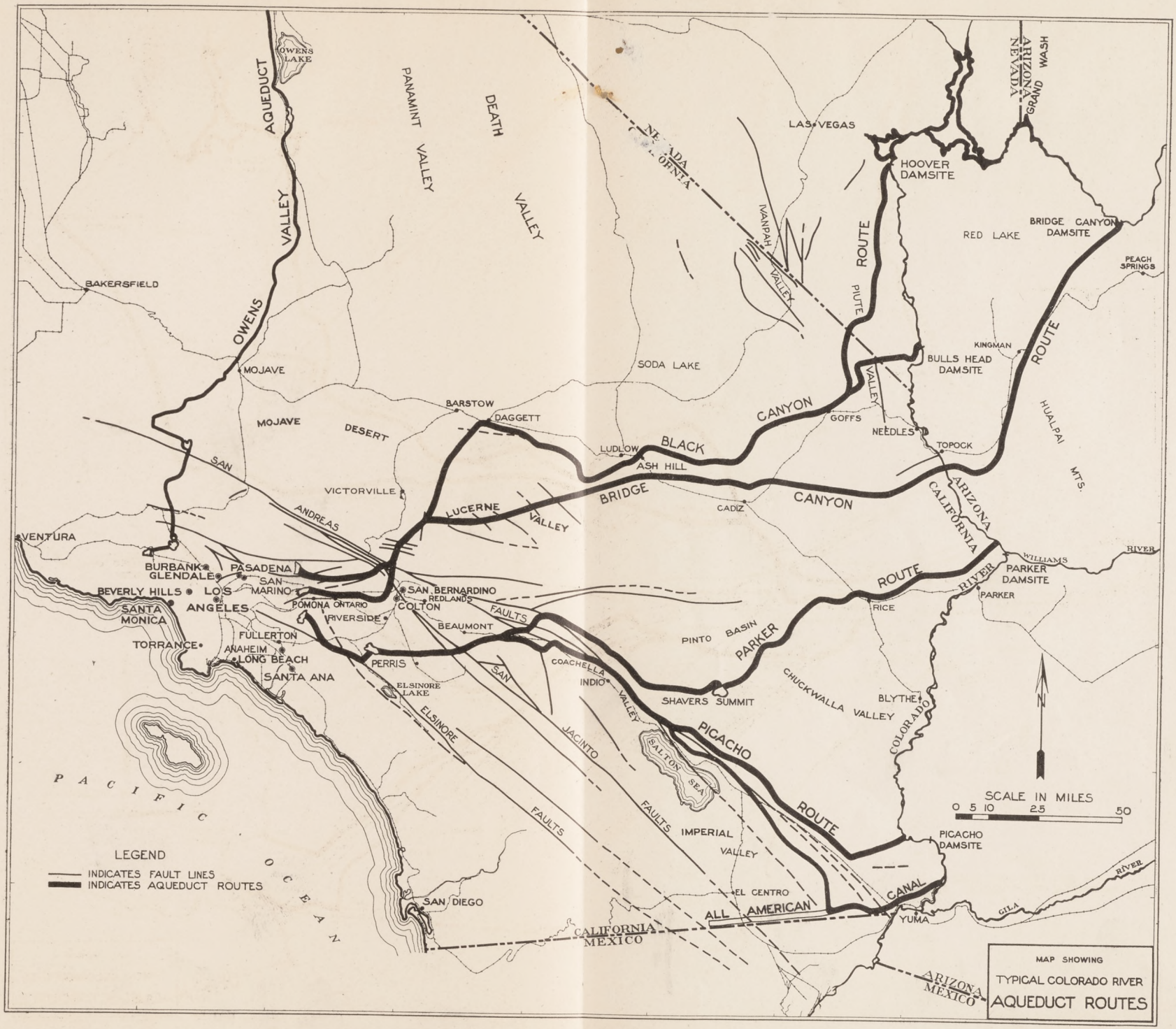
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IVANPAH VALLEY
PIUTE ROUTE
RED LAKE
BRIDGE CANYON DAMSITE
PEACH SPRINGS
BAKERSFIELD
KINGMAN
BULLS HEAD DAMSITE
SODA LAKE
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BARSTOW
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NEEDLES
TOPOCK
HUALPAI MTS.
LUDLOW
BLACK CANYON ROUTE
ASH HILL
SAN ANDREAS
VICTORVILLE
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RICE
SANTA MONICA
BEAUMONT
PINTO BASIN
PARKER ROUTE
TORRANCE
FULLERTON
ANAHEIM
LONG BEACH
SANTA ANA
PERRIS
COACHELLA
INDIO
CHUCKWALLA VALLEY
SHAVERS SUMMIT
BLYTHE
COLORADO RIVER
ELSINORE LAKE
SAN JACINTO FAULTS
ELSINORE FAULTS
SALTON SEA
PICACHO ROUTE
PACIFIC OCEAN
IMPERIAL VALLEY
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